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Transportable seismic array tomography in southeast Australia: Illuminating the transition from Proterozoic to Phanerozoic lithosphere

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ABSTRACT

The Phanerozoic Tasmanides of eastern Australia is comprised of a series of orogenic belts that developed along the east margin of Gondwana following the breakup of the supercontinent Rodinia and subsequent formation of the Pacific Ocean. The tectonic complexities of this region have been well studied, but most work has been confined to evidence collected from the near surface, where extensive Mesozoic and Cenozoic basin cover masks large tracts of Palaeozoic basement. We apply teleseismic tomography to distant earthquake data recorded by WOMBAT – the largest transportable seismic array experiment in the southern hemisphere – to image P-wavespeed variations in the mantle lithosphere beneath the southern portion of the Tasmanides in detail. In order to seamlessly suture together the teleseismic datasets from each of the 14 sub-arrays of WOMBAT, we use P-wavespeeds from the AuSREM model to construct a laterally heterogeneous starting model that captures the long wavelength structural variations that would otherwise be lost through the use of relative arrival time residuals. Synthetic resolution tests indicate good horizontal resolution of ~50 km within most of the array between depths of 50–350 km. A key feature of the 3-D P-wave model is a pronounced easterly high velocity salient in the mantle lithosphere beneath the northern limit of the New England Orocline, which may indicate the presence of underpinning Proterozoic lithosphere that was instrumental in its formation. Another pronounced high velocity anomaly underlies the Curnamona Province, a large crustal block with a strong Archean provenance, which is clearly separated from the Gawler Craton to the west at upper mantle depths by a low velocity zone beneath the Adelaide Fold Belt. We also estimate the location of the eastern boundary of Precambrian Australia at depth, and show that it extends eastward further than previously thought.

1. Introduction

Although less than half of the Palaeozoic basement beneath the southern Tasmanides of eastern Australia is exposed at the surface, a remarkable tectonic history has been progressively revealed over the last century, as more sophisticated techniques and methods of analysis have been brought to bear on an increasingly larger pool of data. Early researchers evidently had a good idea that long timescales and almost unimaginable forces were at work; for instance Schuchert (1916) wrote of the Tasman Sea "It appears that vast land-masses have been fractured, broken up and more or less permanently taken possession of by the oceans", a statement that by today's standards would still be considered accurate given what is known of the opening of the Tasman Sea and the emplacement of the Lord Howe Rise as a rifted continental fragment from the eastern margin of Australia (Gaina et al., 1998). However, the notion of continental drift had yet to enter the early 20th century mindset, and large scale deformation was generally attributed to an Earth that periodically shrinks, with parts of the crust either rising or sinking rather than moving horizontally.

Today, great strides have been made in understanding how the Tasmanides evolved into its current state thanks to advances in many different fields of Earth Sciences including geophysical imaging. For instance, high resolution gravity (e.g. Leaman and Richardson, 1989; Murray et al., 1989; Roach et al., 1993; Spencer, 2004), magnetic (e.g. Glen, 2005; Gunn et al., 1997b; Hill et al., 1997; Mackey et al., 1995; Musgrave and Rawlinson, 2010) and reflection/wide-angle seismic studies (Cayley et al., 2011; Drummond et al., 2000; Finlayson et al., 1998; Korsch et al., 2002; Rawlinson et al., 2001) have been instrumental in probing the Palaeozoic crust and defining the main elements of the southern Tasmanides. Passive seismic imaging has also played an important role, particularly in differentiating between lithosphere of Phanerozoic, Proterozoic and Archean origin. For example, surface wave tomography results from continent-wide broadband deployments reveal that the mantle lithosphere beneath cratonic central and western Australia has markedly higher S-wavespeeds in comparison to the Palaeozoic lithosphere beneath the Tasmanides (Debayle, 1999; Debayle and Kennett, 2000, 2003; Fishwick and Rawlinson, 2012; Fishwick et al., 2005, 2008; Simons et al., 1999, 2002; Zielhuis and van der Hilst, 1996), a result also largely mimicked in P-wavespeed and Q

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as determined from regional body wave tomography (Kennett, 2003; Kennett and Abdullah, 2011). This has allowed constraints to be placed on the boundary between the Tasmanides and cratonic Australia (e.g. Kennett et al., 2004), but there is still considerable uncertainty as to the nature of the transition (Direen and Crawford, 2003b).

A limitation of the Australian continent-wide broadband dataset is that station separation is generally of the order of 200–400 km, which places a restriction on the maximum horizontal resolution to around 200–250 km. Since 1998, a series of targeted experiments – now collectively called WOMBAT – using highly portable short period recorders have been carried out in southeast Australia, with one of the main objectives being to record distant earthquakes for use in teleseismic tomography. With a station spacing of around 50 km or less, a number of studies have revealed detailed patterns of P-wave perturbations in the upper mantle that have allowed the presence of a hot-spot, lithospheric boundaries and continental fragments to be inferred (Clifford et al., 2008; Graeber et al., 2002; Rawlinson and Kennett, 2008; Rawlinson and Urvoy, 2006; Rawlinson et al., 2006a, 2006b, 2010b). Until 2010, these teleseismic datasets were treated separately, but the spatially contiguous nature of the arrays meant that a joint inversion of the datasets would be far more revealing. As such the joint inversion results of Fishwick and Rawlinson (2012), Rawlinson and Fishwick (2012), and Rawlinson et al. (2011) have allowed detailed inferences about the lithosphere beneath Tasmania, Victoria, eastern South Australia and southern New South Wales to be made, including relationships between deep seated anomalies and the distribution of mineral deposits and Cainozoic volcanic centres at the surface.

In this study, we considerably expand on the recent work of Fishwick and Rawlinson (2012), Rawlinson and Fishwick (2012), and Rawlinson et al. (2011) by including data from an additional five arrays in northern NSW and southern South Australia, representing a total of 210 stations or a 53% increase on what was previously available. Furthermore, we also use an improved regional P-wavespeed model (Kennett and Salmon, 2012; Kennett et al., 2013; Salmon et al., 2012) to account for the long wavelength structure that is lost through the use of relative arrival times across multiple arrays. The new P-wavespeed model spans a far greater region of the southern Tasmanides and adjacent cratonic region, and allows new constraints to be placed on the tectonic evolution of Phanerozoic Australia.

2. Tectonic setting

The Tasmanides comprise approximately one-third of the Australian land mass, and is constructed from five Palaeozoic orogenic belts that formed outboard of the Australian section of the east Gondwana — proto-Pacific convergent margin between the Middle Cambrian and the Carboniferous (Cawood, 1982; Glen, 2005). The characterisation and spatial extent of each orogen have been considerably assisted by high resolution gravity and magnetic datasets that have helped overcome the extensive lack of surface outcrop. As a result, rather than showing a map of surface geology, we instead display the distribution of geophysical domains (Fig. 1) as defined by Shaw et al. (1996) based on gravity, magnetic and crustal element boundaries. This has the advantage that major structural variations in the upper crust beneath Mesozoic and Cainozoic cover are revealed, although it is worth noting

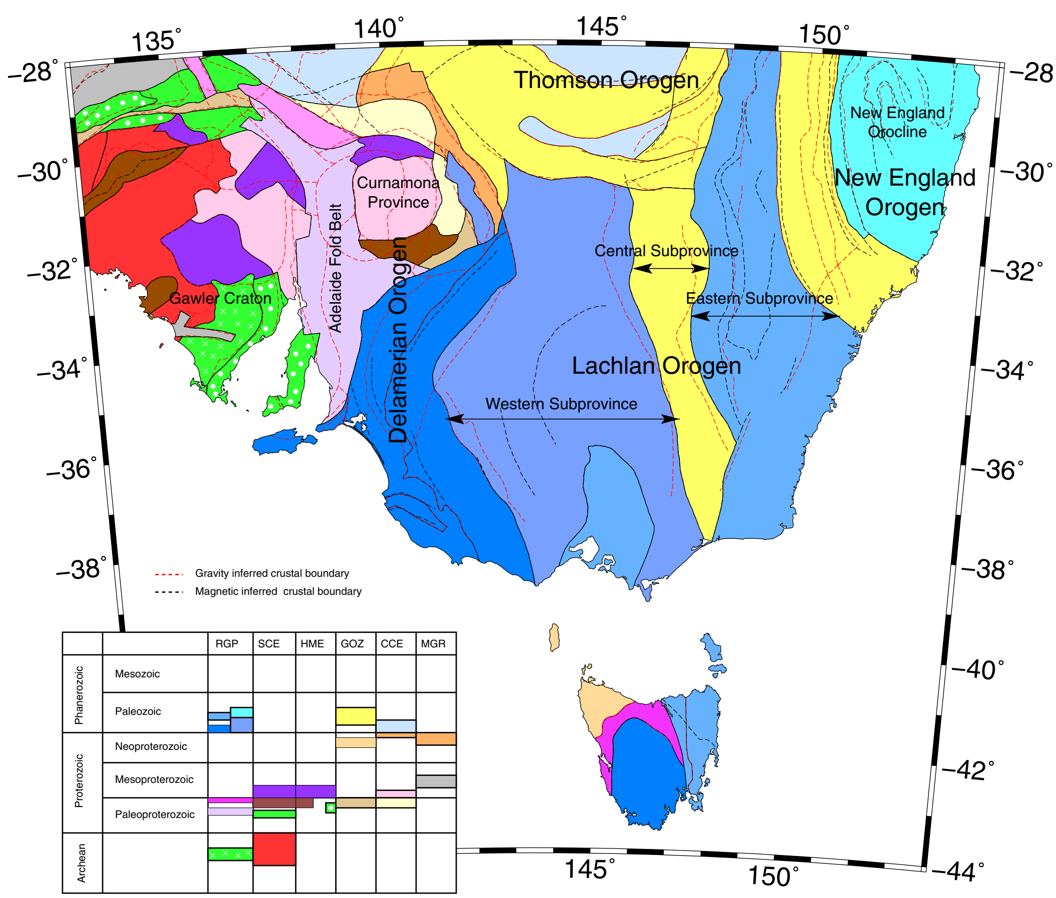

Fig. 1. The crustal elements of southeast Australia, as inferred from potential field data (Shaw et al., 1996). RGP = relict geophysical pattern; SCE = standard crustal element; HME = highly magnetic element; GOZ = geophysically overprinted zone; CCE = covered crustal element; MGR = sub-element with muted geophysical response (see Shaw et al., 1996, for more details).